Current issues of radiation safety regulation for accelerator facilities in Japan

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Introduction

In Japan, the clearance system which contains (1) the clearance level and (2) the control procedures in the radioisotope and accelerator facilities was introduced in regulation of radiation safety.

In this regulation, the definition and the handling rules for activated materials were also defined. Therefore, activation of accelerators, surrounding materials, buildings, air and water should be evaluated and controlled.

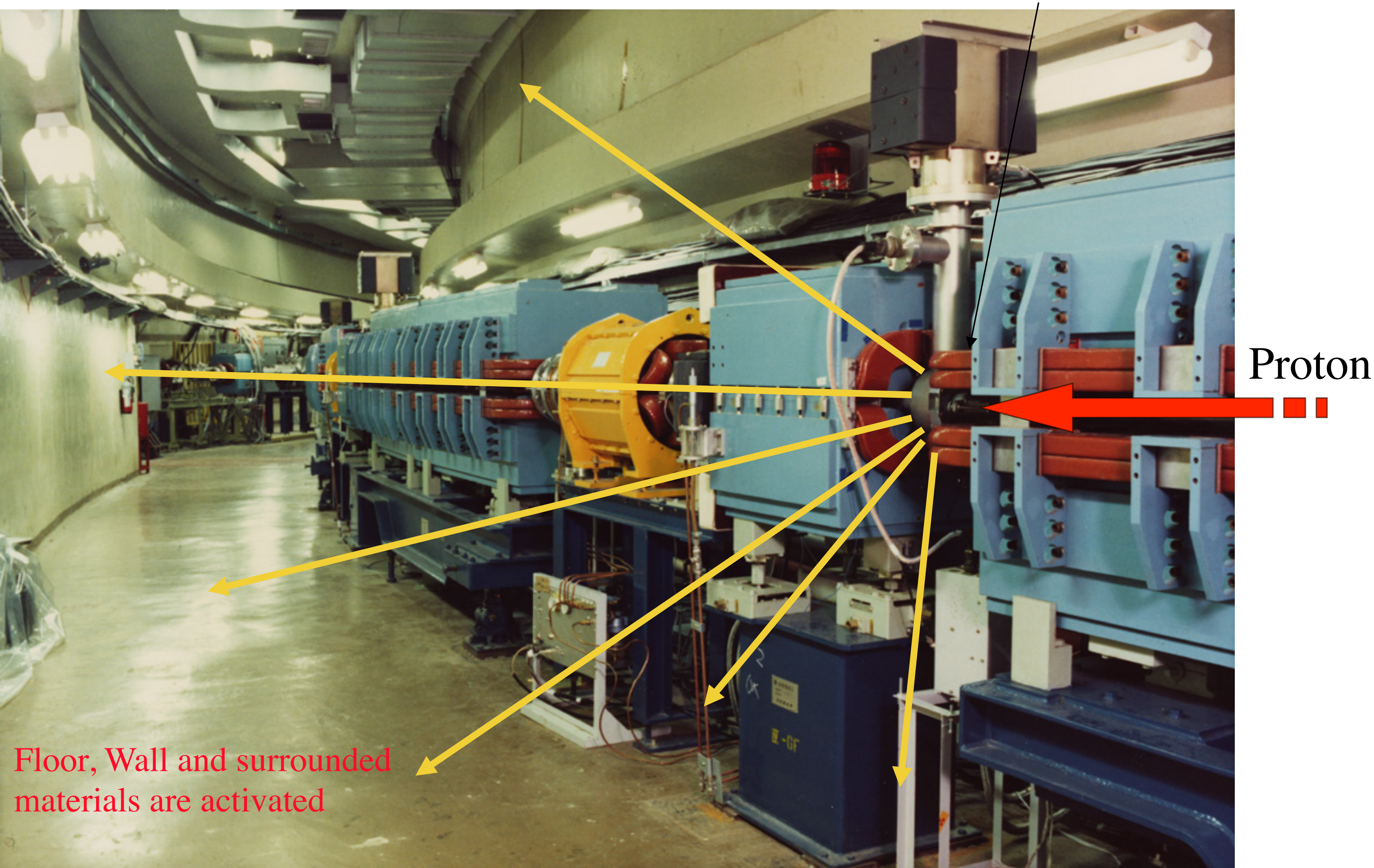
Motivation of clearance

- During operation of accelerator -> Surrounding materials are activated by the beam loss
- Primary beam -> Limited area is highly activated
    -> Secondary particles (Neutrons) are emitted
- Activation by neutrons -> Induced activity is low, but very wide and deep area are activated
- Decontamination -> Large volume of concrete
- High energy, High intensity -> Severe problem

(12 GeV PS -> concrete : several 10,000 tons)

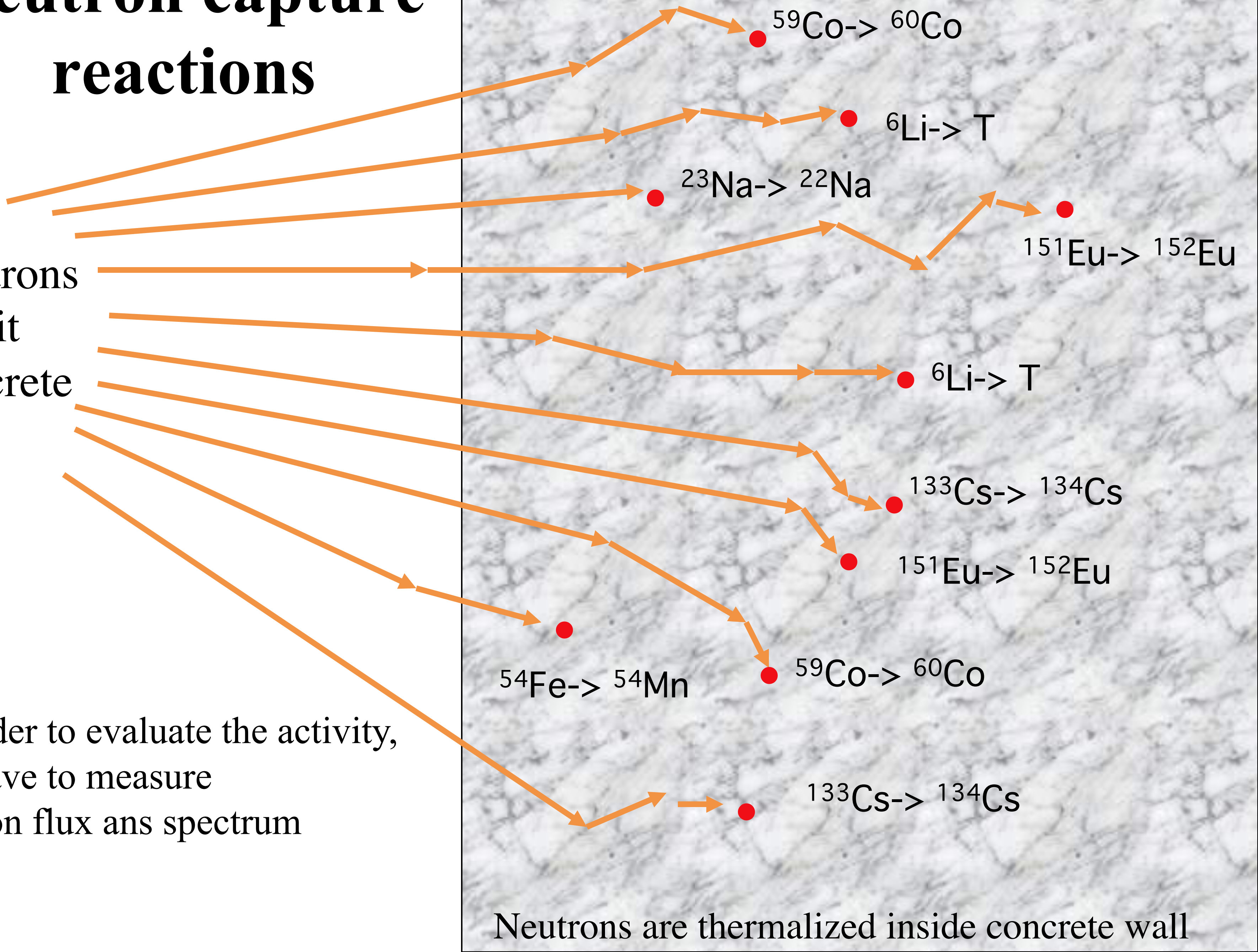
Activation mechanism

Neutrons are emitted at
the beam loss points



Neutron capture reactions

Neutrons hit concrete



In or der to evaluate the activity,
We have to measure
neutron flux ans spectrum

Purpose

- Evaluation of the amount of activated materials -> to help the calculation of the clearance level for the accelerator facility.
- Concrete samples from several types of electron and hardon accelerators were collected.

  -> Radioactivity in these samples were determined.
- Comparison of induced activities between accelerator types (particle, energy and power).
- Estimation of neutron fluence.

Accelerator Facilities

- Proton accelerator

1) Shimadzu MCY- 1750 cyclotron (17 MeV) , JRIA
2) SF-cyclotron (45 MeV), CNS, the Univ. of Tokyo
3) AVF cyclotron (65 MeV) and Ring cyclotron (400 MeV), RCNP, Osaka Univ.
4) 12-GeV Proton synchrotron, KEK

- Electron accelerator

1) 45-MeV electron linear accelerator, Hokkaido Univ.
2) 300-MeV electron linear accelerator (220 MeV), Tohoku Univ.
3) 1.3-GeV Electron Synchrotron, Tanashi, KEK

Experimental

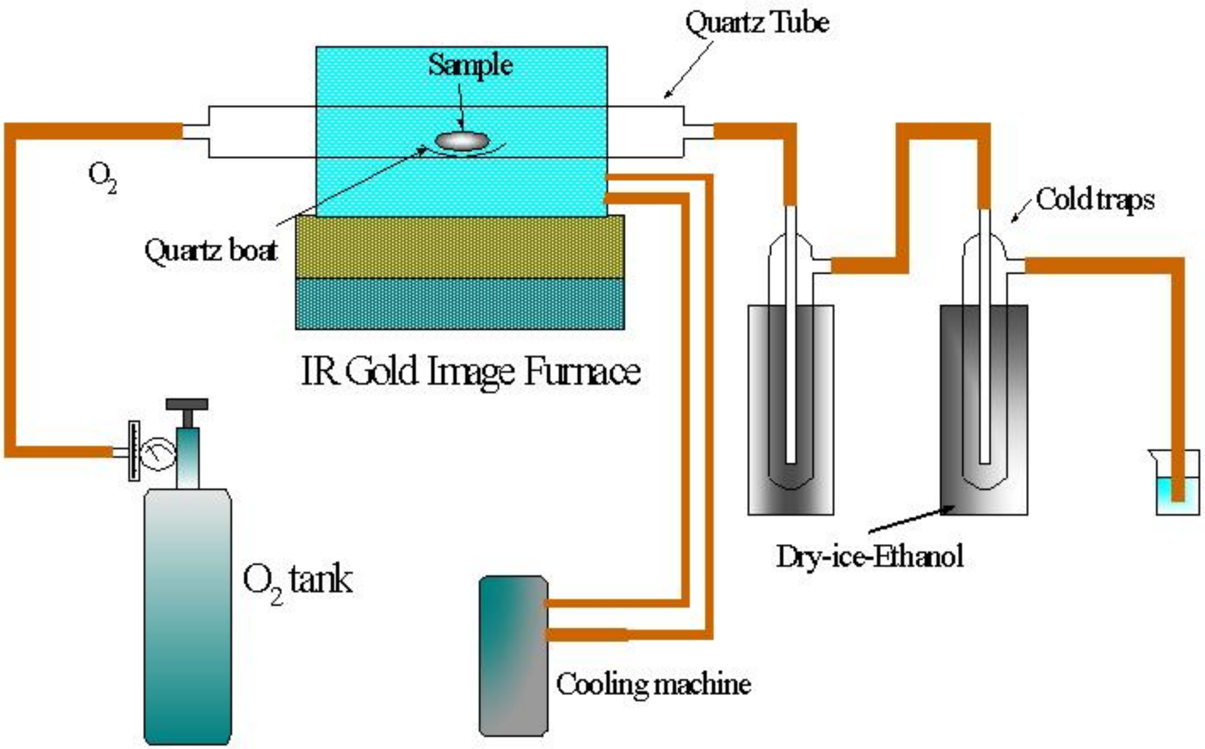
- Core samples (Sliced and Powdered)
- Surface concrete (Cut and Powdered)

(1) Gamma-ray spectrometry
(2) Tritium activity measurement
(3) Determination of $^{36}Cl/^{35}Cl$ by AMS
(4) Elemental analysis by NAA and AAS
(5) Other nuclides (C-14, Ni-63)

Sampling

Gamma-ray measurement

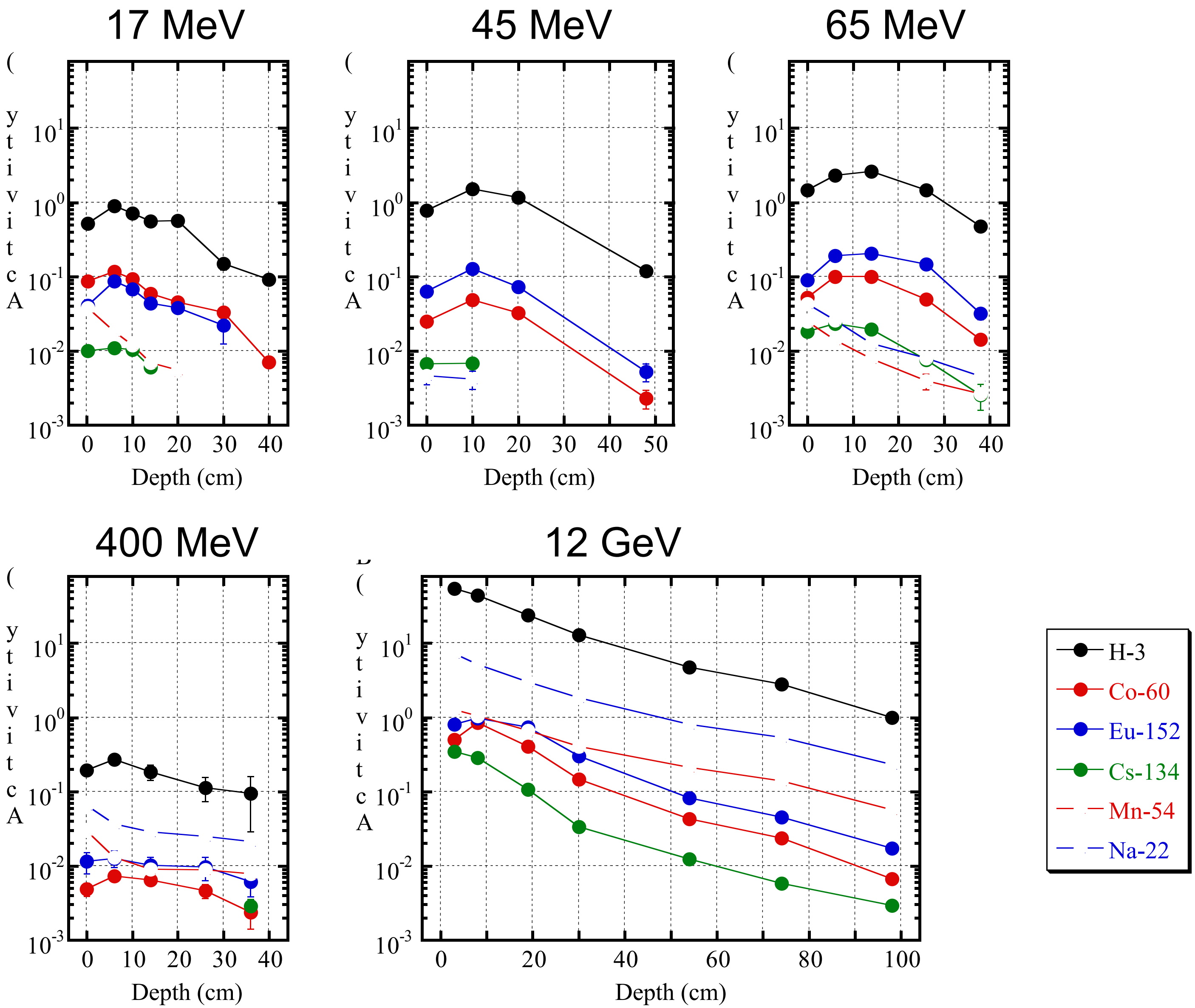
Extraction of Tritium



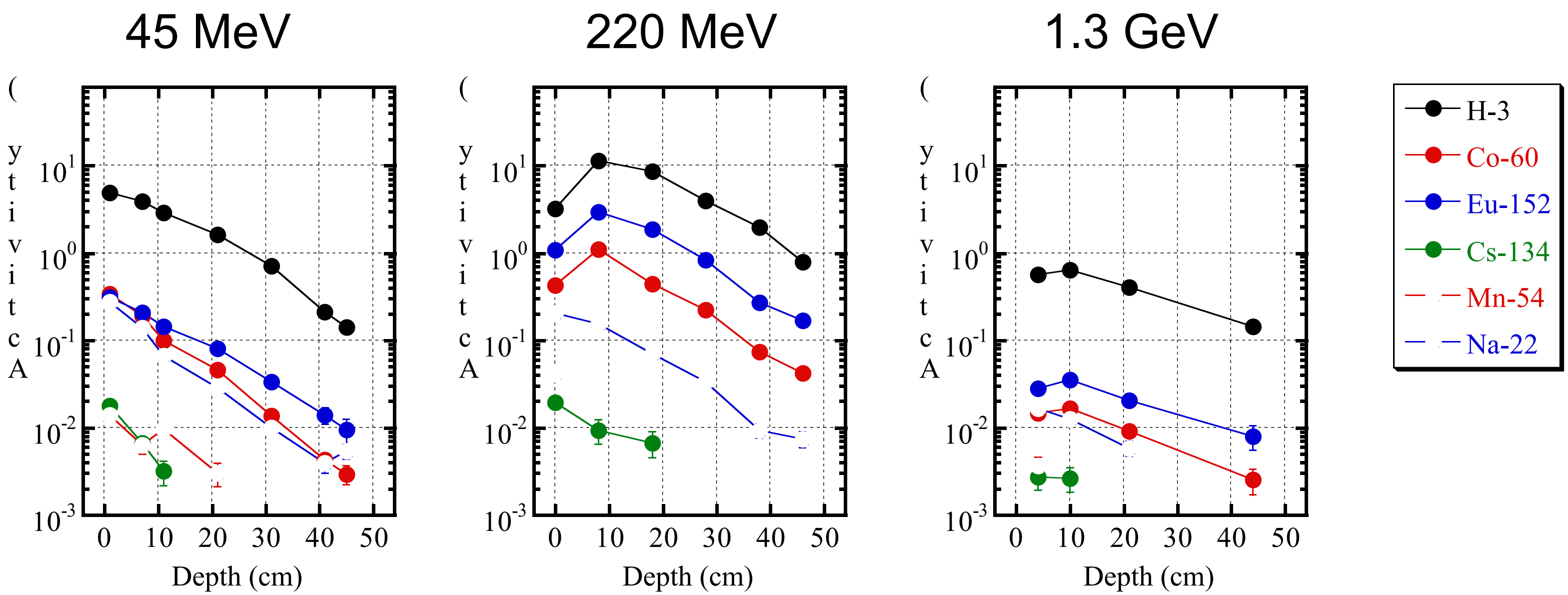
Achievement of rapid, simple, reproducibility by using IR furnace

Cl-36 analysis by AMS

- Cross-section=1/v Laws -> Estimation of thermal neutron fluence
- Long half-life (3.01×10^5 y) -> Integral of neutrons during operation
- AMS result -> $^{36}Cl/^{35}Cl$ -> Specific activity
- Development of Cl-36 separation and purification from concrete samples
- AMS was performed at the accelerator center, Univ. of Tsukuba



Depth profiles of several nuclides - Proton accelerator facilities

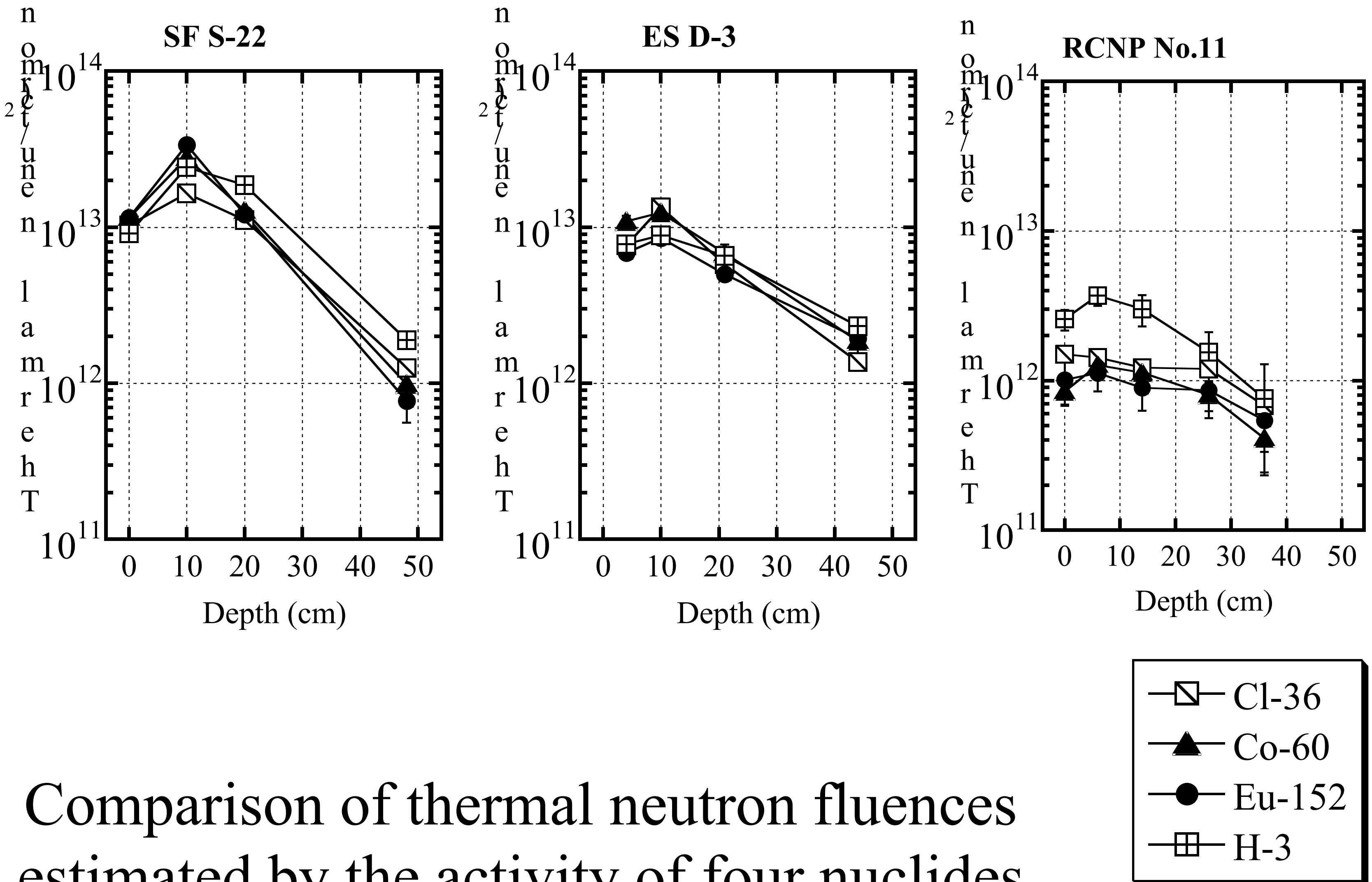


Depth profiles of several nuclides - Electron accelerator facilities

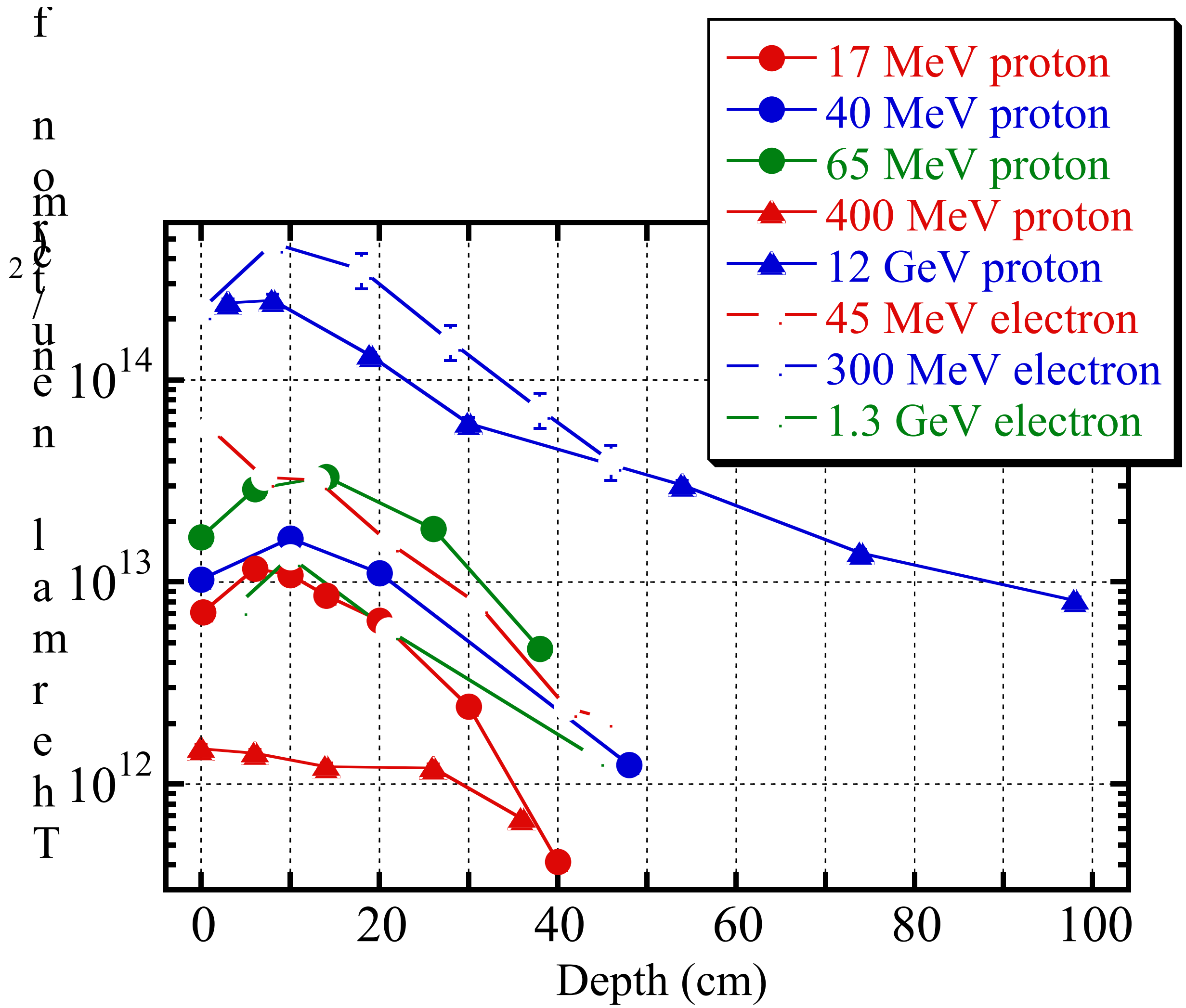
Elemental analysis of concrete

- Elemental composition of concrete from 7 facilities were almost same.

- Eu ; 0.4 - 0.9 ppm -> Eu-152, 154
- Co ; 6 - 20 ppm -> Co-60
- Cs ; 1.2 - 4.5 ppm -> Cs-134
- Li ; 5 - 15 ppm -> T



Comparison of thermal neutron fluences estimated by the activity of four nuclides



Thermal neutron fluences in concrete of various accelerator facilities

Total Neutron Fluence

- Thermal neutron fluences were calculated by the yield of Cl-36.
- Results from Co-60, Eu-152 are almost same as that from Cl-36.
- Tritium in produced by $^{7}Li(n,\alpha)$reaction and spallation reaction.
- Total neutrons were 10^{13} to 10^{15} at the highly activated area of 7 accelerator facilities.

Result of concrete analysis

(1) Major nuclides : ^{60}Co, ^{152}Eu and ^{3}H. Activity of ^{3}H is one order higher than ^{60}Co, ^{152}Eu .

(2) Major reaction : Thermal neutron capture

(3) Maximum activity was observed at the depth of 10 to 20 cm.

(4) ^{36}Cl/^{35}Cl shows the same depth profile. Yield of^{36}Cl is effective to obtaine the neutron fluence from the bigining.

(5) ^{22}Na, ^{54}Mn are produced by fast neutron reactions and observed near the beam loss points. These activities are decreased exponentially.

(6) Similar results were obtained both electron and proton accelerators.

Clearance level

- Material estimation (metal, concrete,,,)
- Volume estimation (tons/facility)
- Nuclides estimation (^{60}Co, ^{54}Mn, ^{22}Na,,,)
- Chemical, Physical state estimation
- Senario estimation (reuse, storage,,,)
- Dose calculation (10μSv/y)
- CL -> RS-G-1.7(IAEA)

Clearance procedure

- Clearance proposal to government
- <- Check the procedure and their QC/ QA
- Decommissioning
- Remove radioactive mateials
- Separate clearance level materials
- <- Check by the government
- Release after receiving the permission

Proposal of zoning

- Clearance procedure is time consuming and not cost effetive.
- It was difficult to perform at the small facilities.
- Then, we defined the non activated area by zoning, especially in hospitals.

Number of accelerators in Japan (as of March 31, 2015)

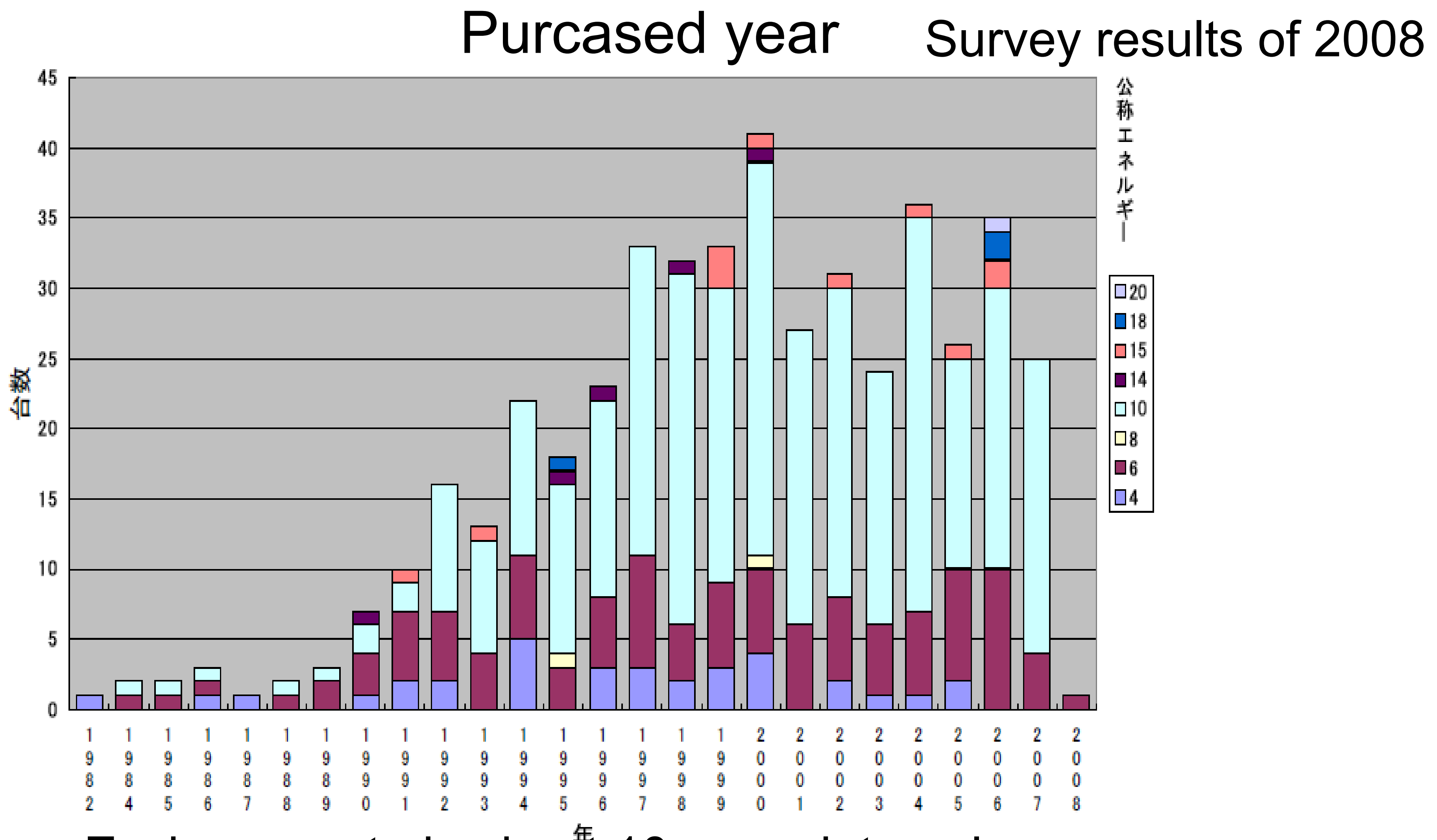
Category	Total	Hospitals &Clinics	Educational Institutions	Reseach Institutions	Private Companies	Other Organizations
Total	1,595	1,180	66	165	147	37
(%)	100%	74	4.1	10.3	9.2	2.3
Cyclotrons	212(13.3)	143	4	23	39	3
Synchrotrons	40(2.5)	9	3	23	4	1
Synchrocyclotrons	-	-	-	-	-	-
Linear Accelerators	1,202(75.4)	1024	25	55	65	33
Betatrons	3(0.2)	–	1	2	-	–
Van de Graaff Accelerators	38(2.4)	–	14	23	1	–
Cockcroft-Walton Accelerators	73(4.6)	–	16	27	30	–
Transformer-type Accelerators	17(1.1)	–	–	9	8	–
Microtrons	9(0.6)	4	3	2	–	–
Plasma Generators	1(0.1)	–	–	1	–	–

- How to keep the medical use.

-> Activated area should be defined for the decommissioning work in hospitals. But, it is very difficult to do in hospitals.

- Then, we performed the neutron monitoring using activation detector, TLD, CR-39 in hospitals.
- Calculation of activation has been also done by the coupling use of Monte Calro methods and Dchain-SP.

Electron Accelerators in Hospitals

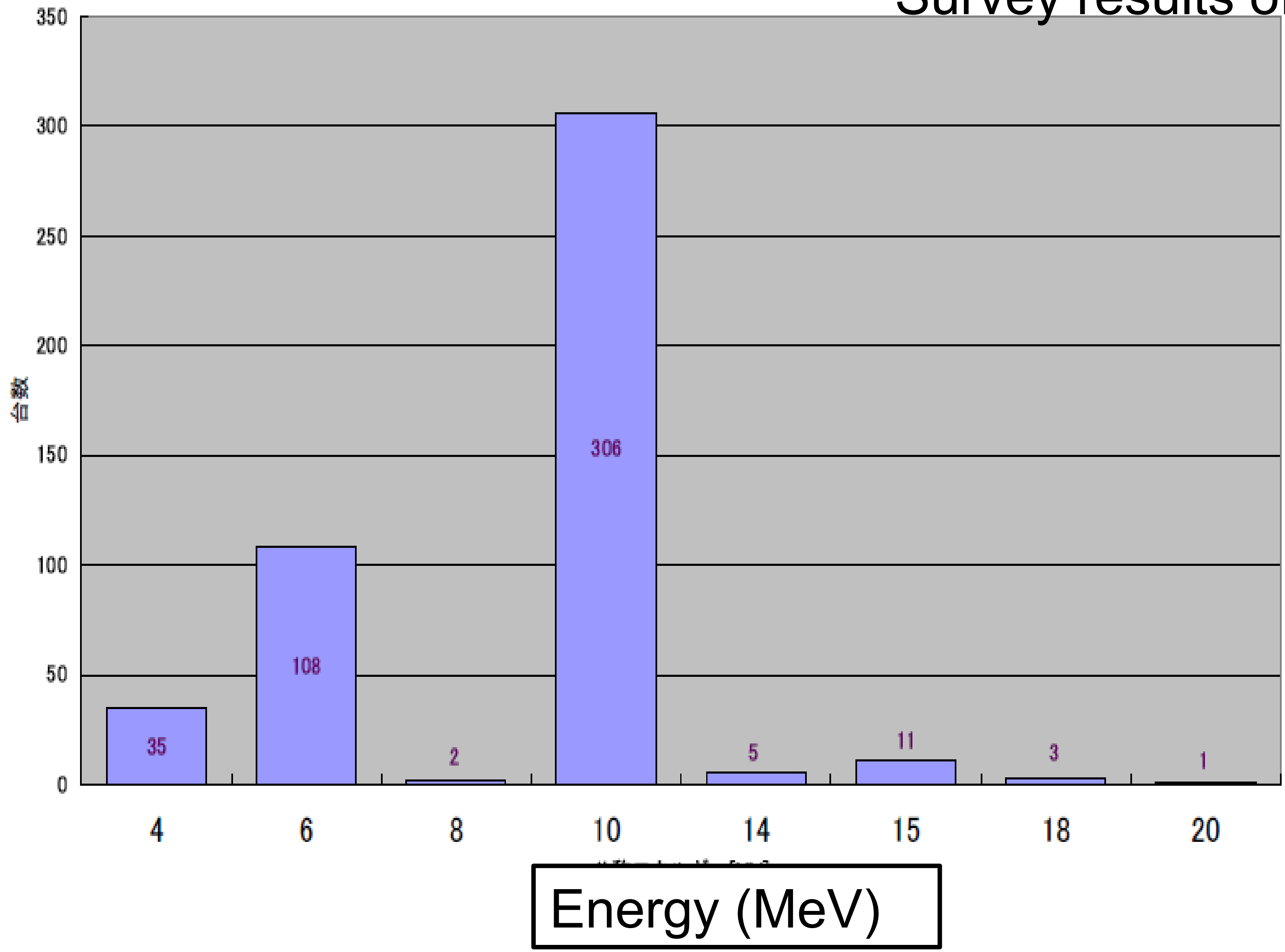


Exchange rate is about 10 years interval.

100 mashines were exchanged per 1 year in Japan.

X-ray maximum energy

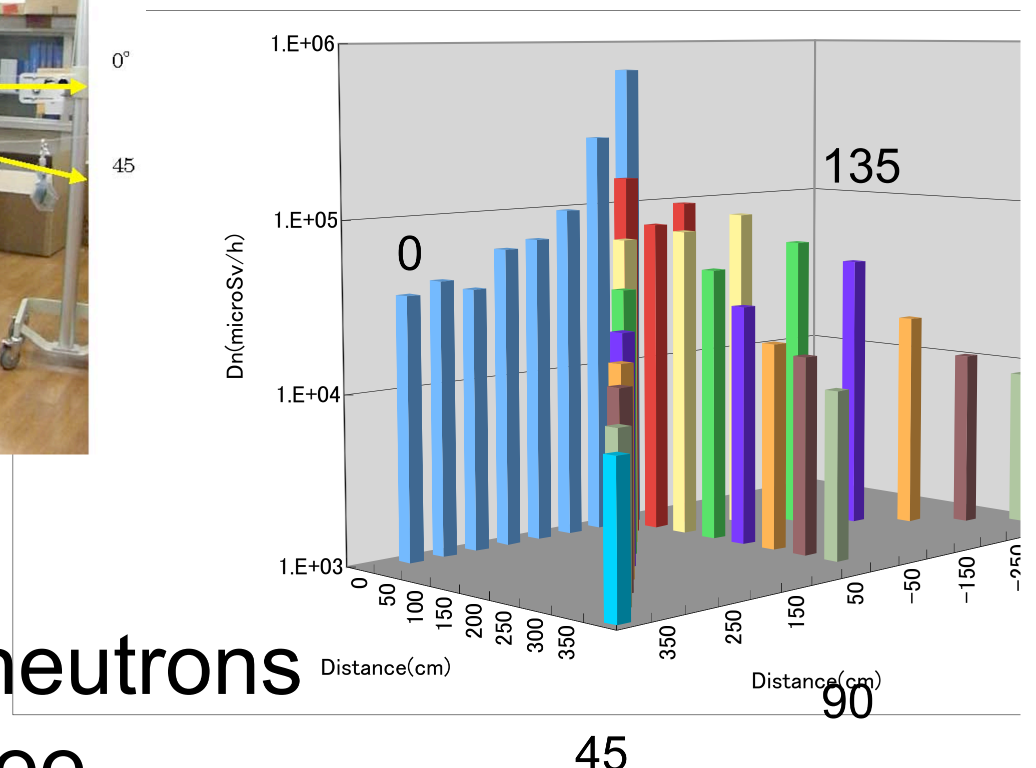
Survey results of 2008



Neutron measurement

- Dose
  - TLD；UD-813PQ4
  - Track detector : CR-39
    conversion from Sv to fluence
- Neutron fluence
  - Au-foils (20μm in thickness)
    + covered with and without
    Cd-foils(0.5mm in thickness)

Varian Clinac iX (15 MeV)



Dose monitoring of neutrons
X-ray beam -> 0 dgree
Neutrons -> isometric

Comparison C/E

E decreased more rapidly than C (MCNP)

C/E<2

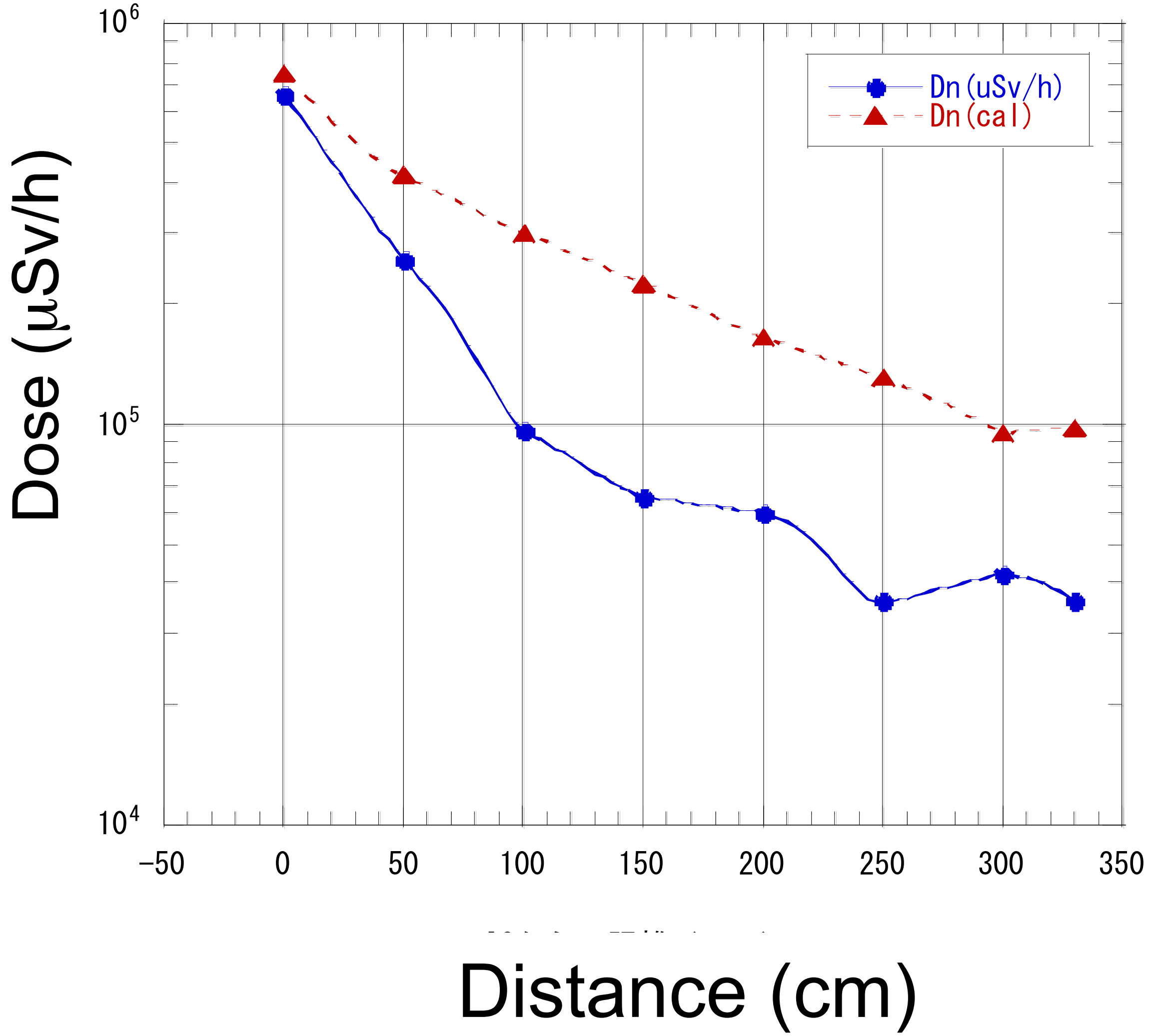
Bolt(SUS304) of floor

Co-60: 0.016 Bq/g

10y、400hr/y operation

C=0.029Bq/g

(C/E=1.8)

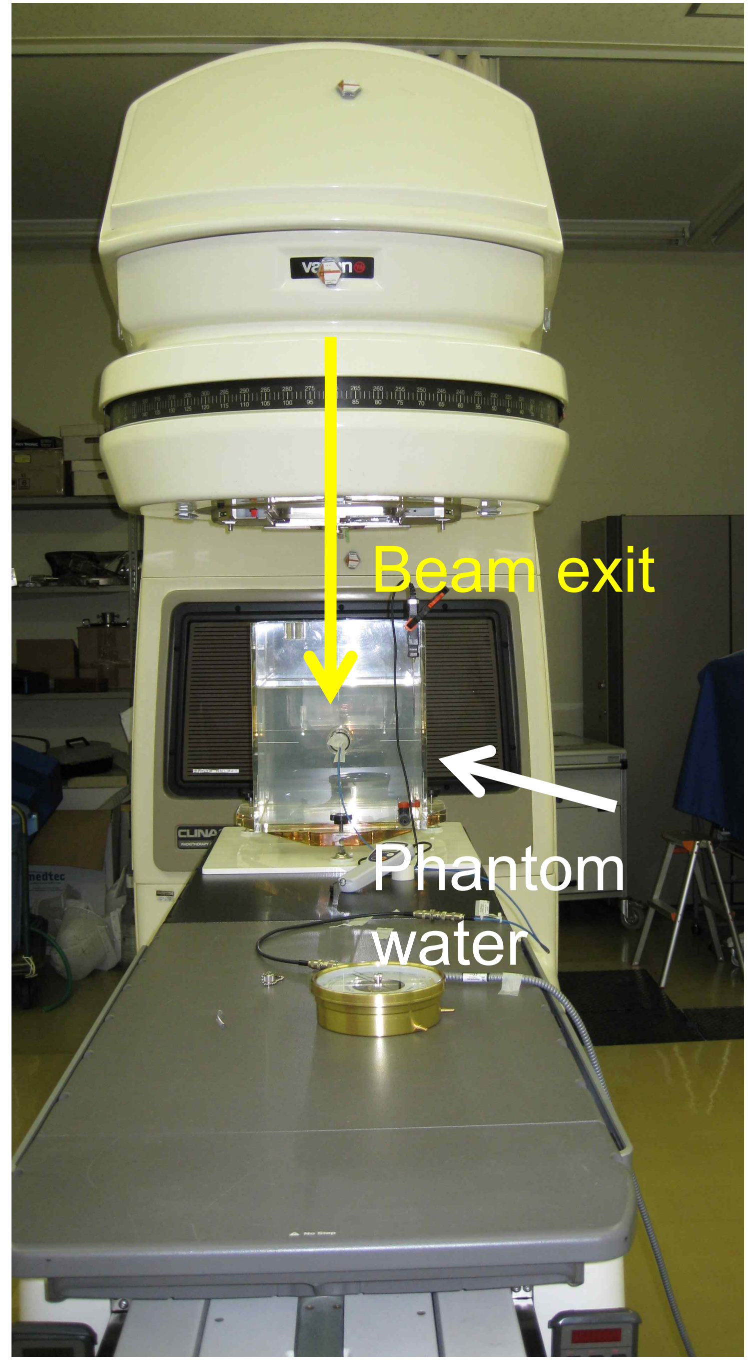


Neutron dose (15MeV, 0-degree)

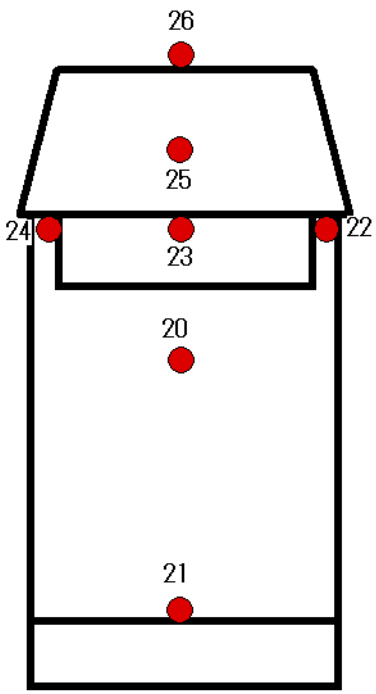
Neutron monitoring at 18 MeV

Varian Clinac 2300 C/D 18MeV
1 min. irradiation

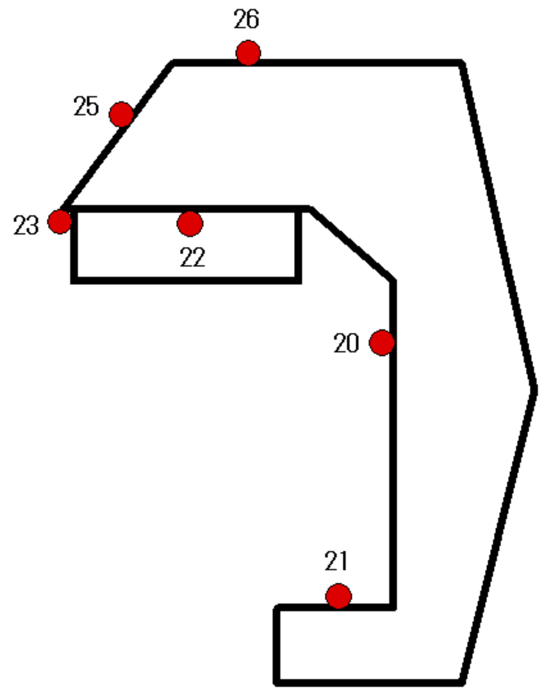
Run-1:electron(without target)
Run-2:X-ray（window: 40cm×40cm）
Run-3:X-ray（with Multi lleef）
Run-4:X-ray（with steel filter）
Run-5:X-ray（with Pb filter）
Run-6:X-ray（window : 0.5cm×0.5cm）



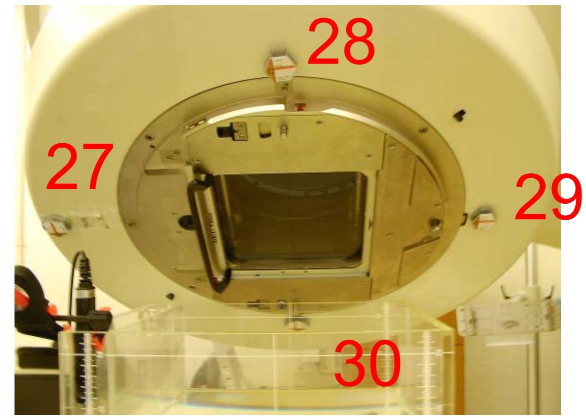
Measurement position

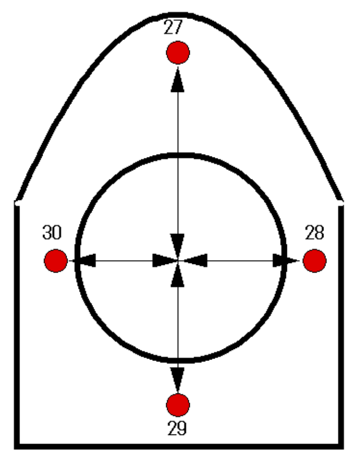


Front viw



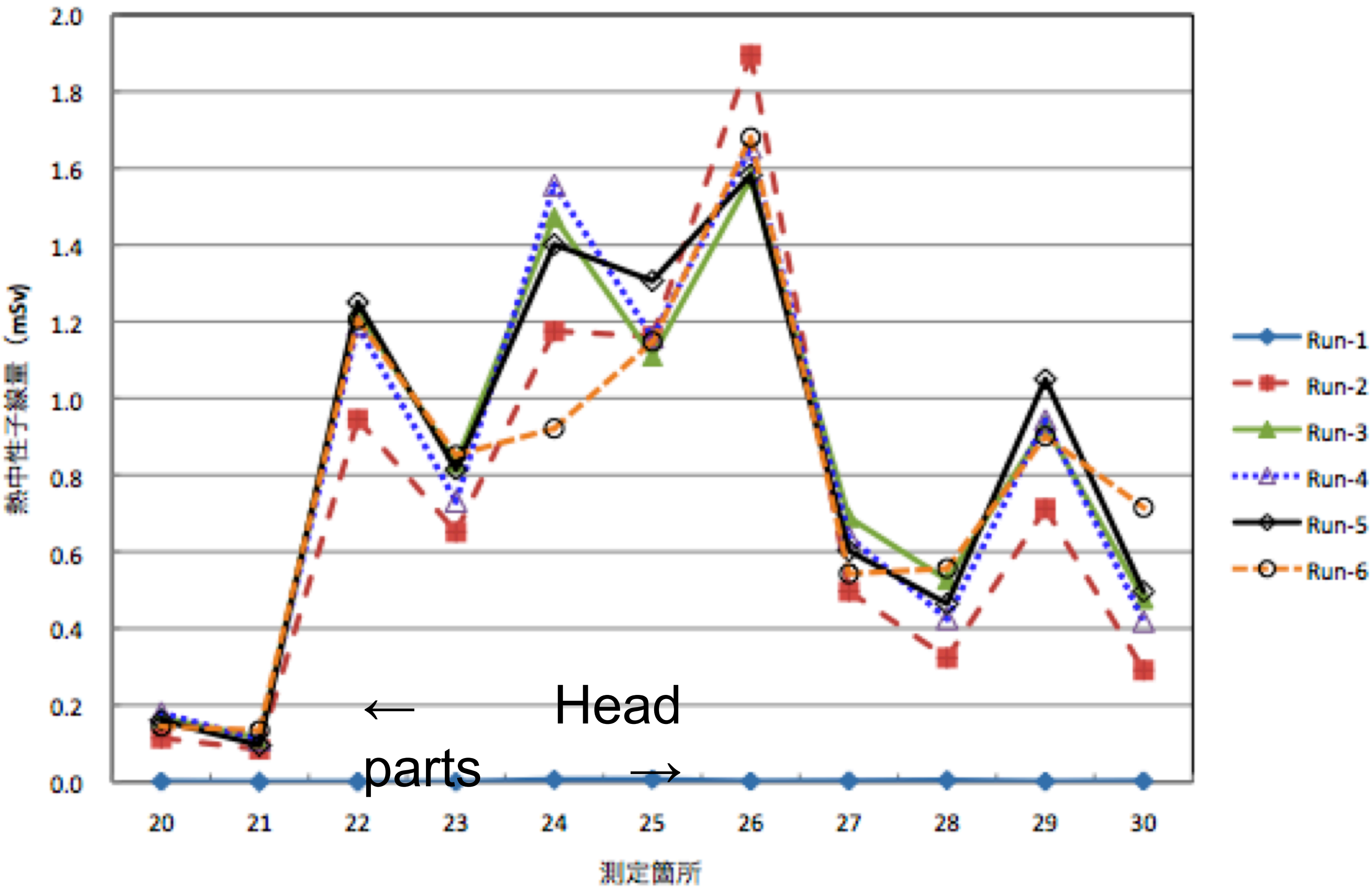
Side viw





Head beneath

Thermal neutron

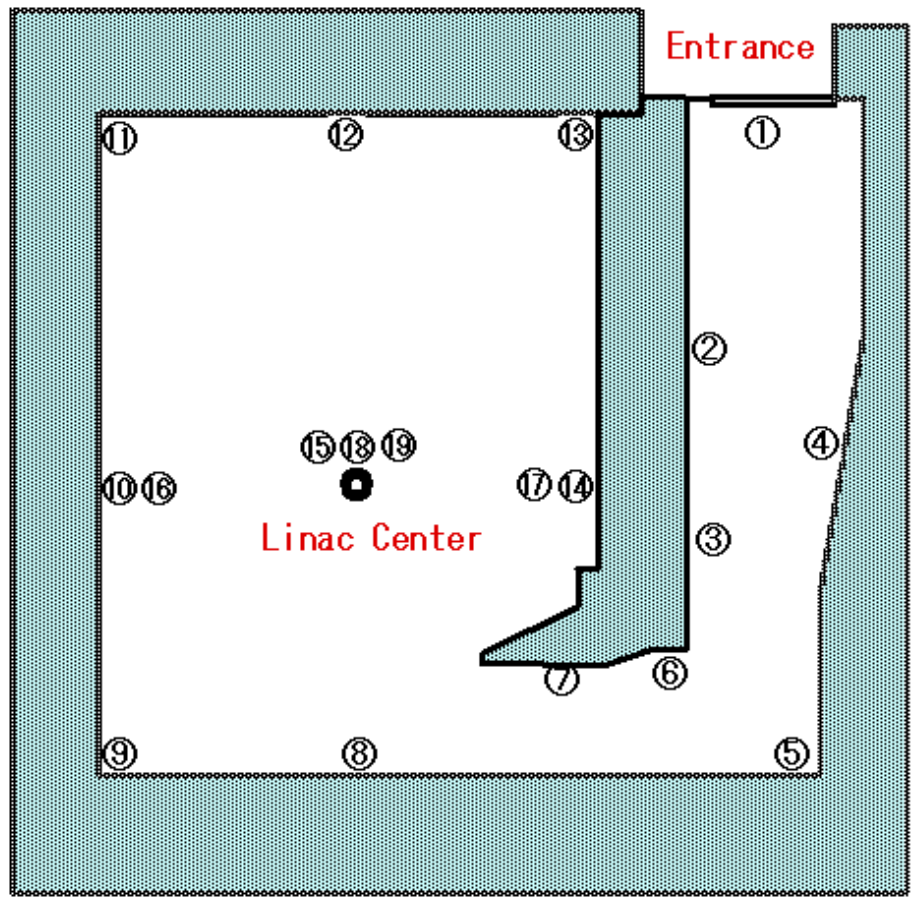


High fluence at No. 22, 24 and 26

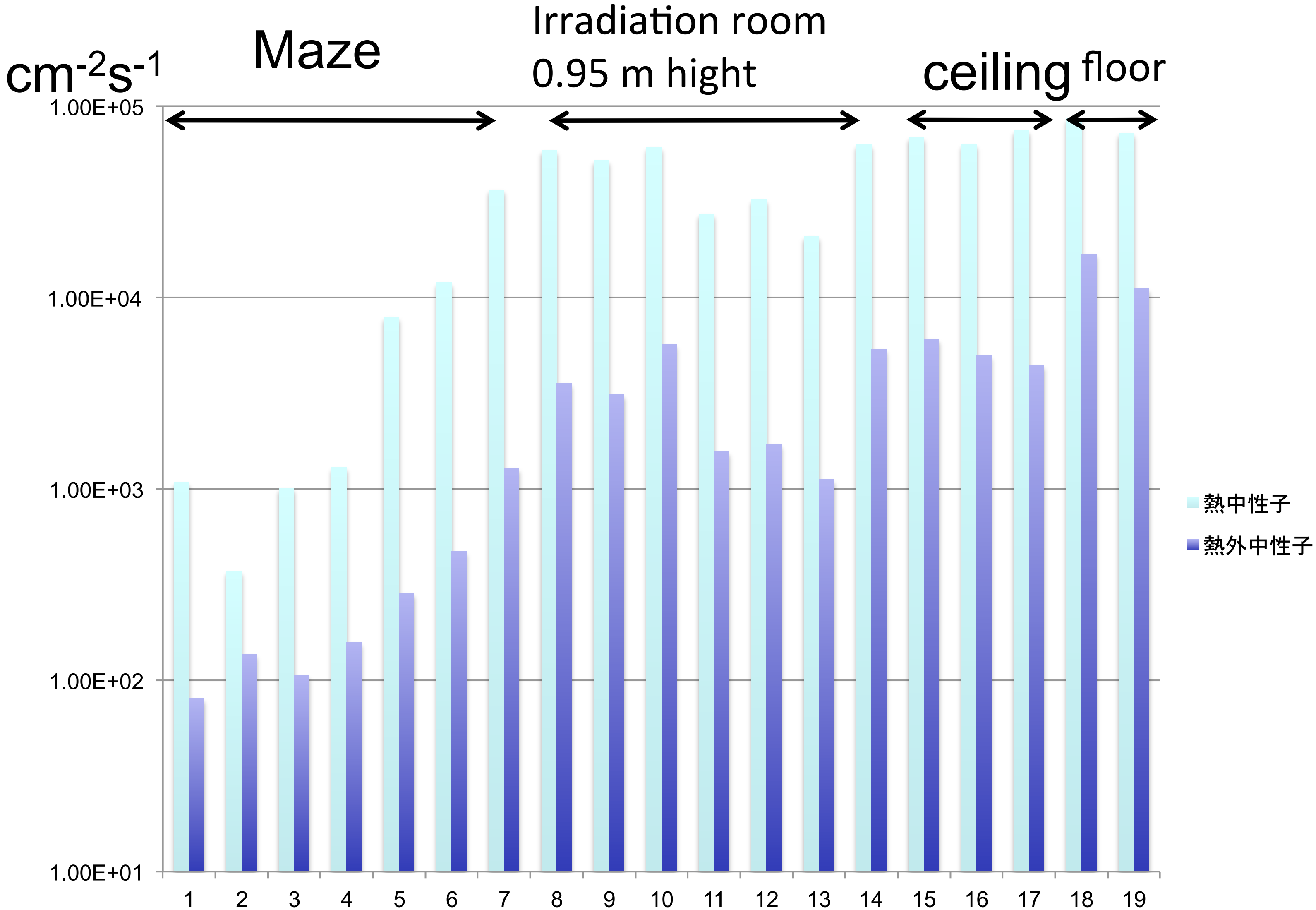
Neutron distribution

Au、TLD、CR-39 were set for 1d.

Total operation time=11.1min



Thermal neutron distribution



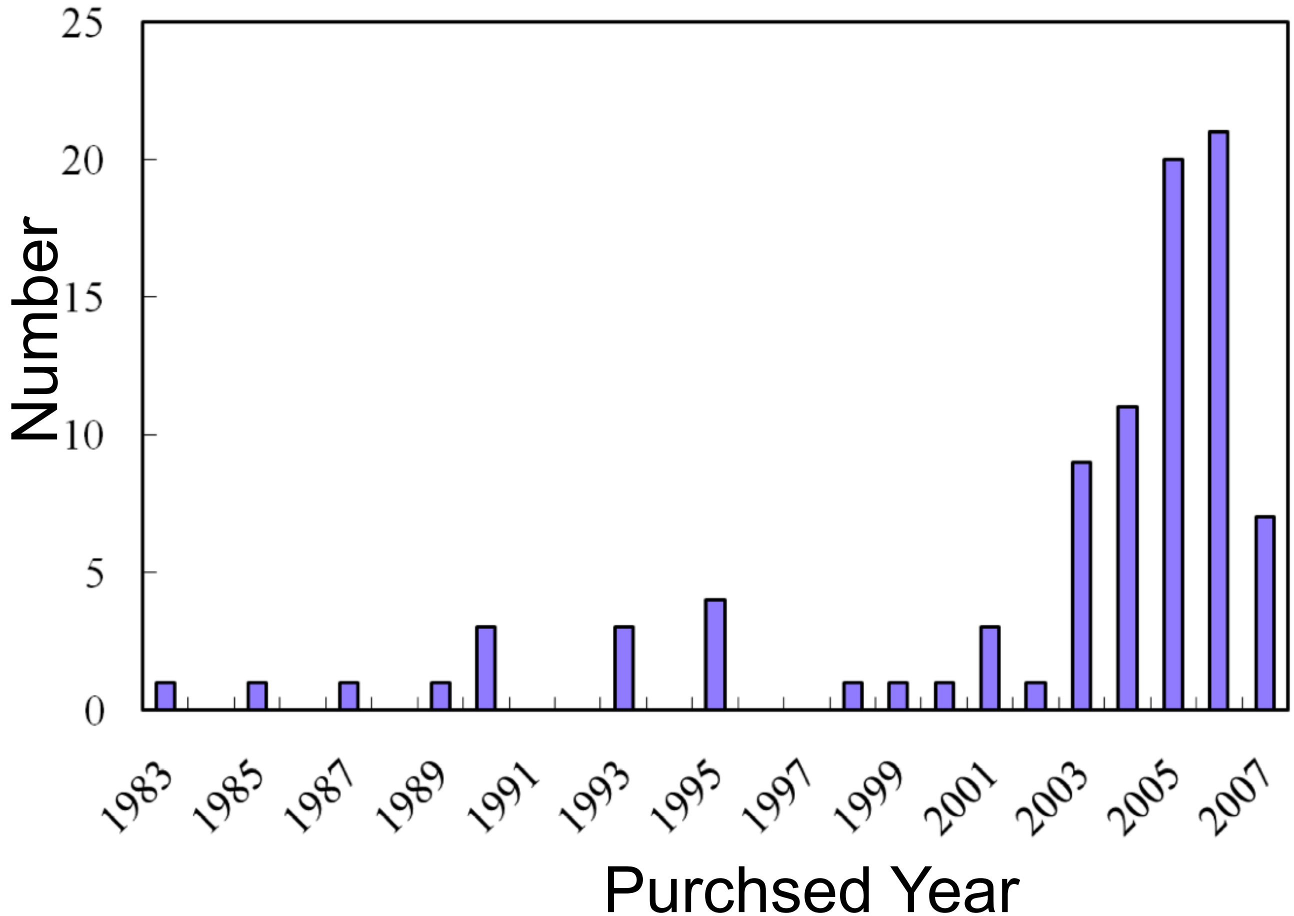
Our results

X-ray energy(MeV)	Neutron flux
6	ND
10	Thermal:$1X10^3 cm^{-2}s^{-1}$、Epithermal:$1X10^2 cm^{-2}s^{-1}$ Thermal 10^6 cm^{-2} (d)、10^{10} cm^{-2} (10y)
15	Thermal:$2X10^4 cm^{-2}s^{-1}$、Epithermal:$2X10^3 cm^{-2}s^{-1}$ Thermal $10^{7-8} cm^{-2}$(d)、10^{11} cm^{-2}(10y)
18	Thermal:$5X10^4 cm^{-2}s^{-1}$、Epithermal:$4X10^3 cm^{-2}s^{-1}$ Thermal 10^8 cm^{-}(d) 、10^{11} cm^{-2}(10y)

Activated area assigned by NSA

- 6 MeV :No activation
- 10 MeV or less : target and collimators
- 15 MeV or less : target, collimators and shielding materials
- Non activated region -> Surroundings and Building

PET cyclotron



- Peak: 2005
- After 2007, delively system was prevailed.
- Now, decommisiong case was increased.

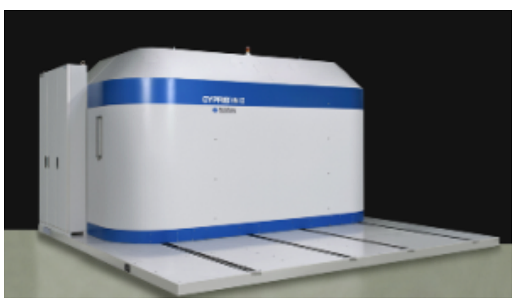
Cyclotron

(a) Proton

(b) H^{-1} ion

without self-shield

Self-shield



RI production and reaction

Produced RI	Reaction	Site number
^{18}F	$^{18}O(p,n)^{18}F$ $^{20}Ne(d,\alpha)^{18}F$ $^{18}O(p,n)^{18}F$, $^{20}Ne(d,\alpha)^{18}F$両方	82 1 4
^{11}C	$^{14}N(p,\alpha)^{11}C$	29
^{15}O	$^{14}N(d,n)^{15}O$ $^{15}N(p,n)^{15}O$	17 5
^{13}N	$^{16}O(p,\alpha)^{13}N$	15
Others	$^{64}Ni(p,n)^{64}Cu$	1

^{18}F is major RI

^{11}C(33%)、^{15}O(25%)、^{13}N(17%)

Source of neutrons of PET-cyclotron

- Neutrons are mainly produced by the $^{18}O(p,n)^{18}F$ reaction.
- Neutron yield from the $^{14}N(p,\alpha)^{11}C$ reaction was 8.9% of ^{18}F-production
- Therefore, neutron fluence is mainly dependent on the produced amount of ^{18}F.

Measurement of neutron fluence

SHI　HM-18

Target:water（O-18）

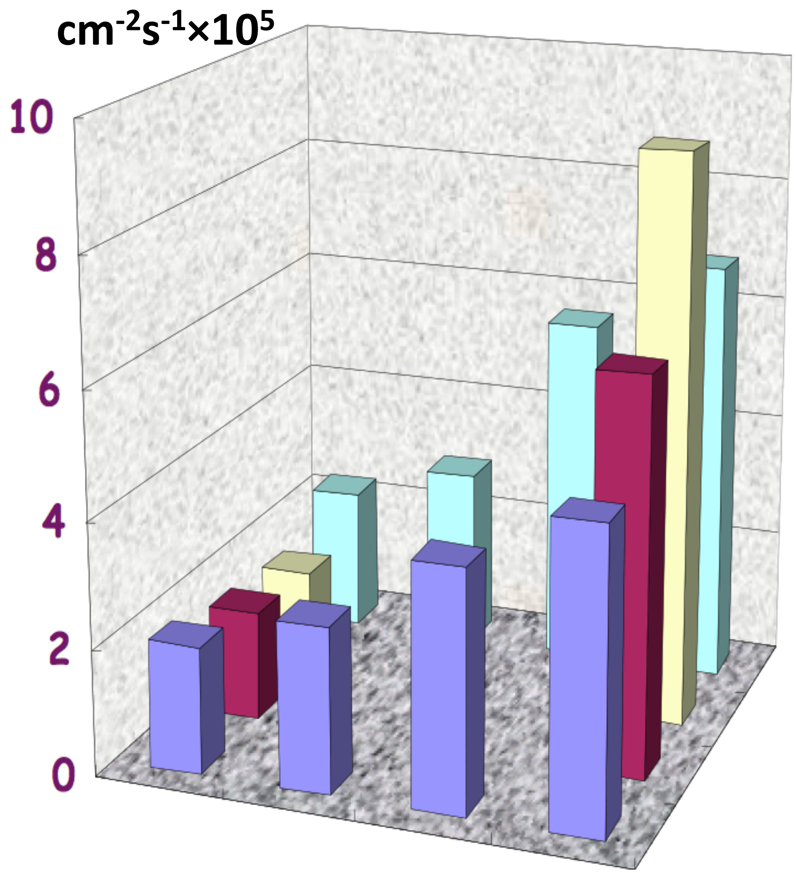
Production：F-18

H^- ion，18MeV

Current：21μA

Irradiation：63min

Neutron distribution



Near target : 10^6 $cm^{-2}s^{-1}$
Opposite side : 2×10^5 $cm^{-2}s^{-1}$
Inside the target box : 10^7 $cm^{-2}s^{-1}$

Bolt(Brass,Cu:Zn=65:35) was sampled from the wall near the target
Averaged neutron flux of operation
Cu-64 : 4.5×10^5 $cm^{-2}s^{-1}$ (2days)
Zn-65 : 6.3×10^5 $cm^{-2}s^{-1}$(2years)

Results

- Near target: $10^{7}cm^{-2}s^{-1}$
- Inside the vault: $10^{5-6}\ cm^{-2}s^{-1}$

- Estimation of induced activity in concrete
  - Co :10ppm
  - Operation:500h/year
  - Neutron flux= 4.6×10^{5}

  Specific activity of Co-60 became 0.1Bq/g.

Outside of self-shield

- CR-39, TLD were set for one month
- Thermal neutron dose rate on operation： several μSv/h
- Thermal neutron flux on operation： under $10^{2}cm^{-2} \cdot s^{-1}$
- Activation by neutrons is negligibly small.

Zoning of PET-cyclotrons

- Without self-shield
  - Inside the vault is activated area

- Self-shield type
  - No activated area : Outside the self-shield
  - Activated area : Inside the self-shield

Conclusion

- Neutron measurement during operation is very effective to estimate activation of surrounding materials.
- To estimate induced activity, operation record is also important.
- We will define the activation zone in the facilities of SR, Tandem, Particle therapy as the next step.